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Color schlieren with a crystalline lens

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Abstract

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COLOR SCHLIEREN
WITH A
CRYSTALLINE LENS

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BY

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ADVISOR:

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LITERATURE REVIEW

There is very little in the way of literature on this subject. However, there were four articles that helped to formulate the idea for this research. They are as follows:

1. "Model of Refractive Index Distribution in the Rabbit Crystalline Lens", by Shuitu Nakao, Shigeru Fujimoto, Ryo Nagata, and Koiti Iwata in the Journal of the Optical Society of America, Volume 58, number 8, August 1968.

In this paper, an optical system developed by Nagata in 1964 was used to measure the gradient of refractive indices in two-dimensions (in the horizontal plane and in the equatorial plane of the lens) in the crystalline lens of the rabbit, and rays were traced on the models obtained from the experiments which showed the spherical aberrations present in the lenses.

The experiments showed that there were many iso-indicial layers with each layer having constant index. Between successive layers, the difference of refractive indices was constant.

The spherical aberrations of the average model was remarkably smaller than that of the model which has uniform refractive index. These results show that the nonuniform distribution of indices in the crystalline lens serves to reduce its spherical aberration and to increase its refractive power.

2. "Calculation of Three-Dimensional Refractive Index Distribution from Interferograms", by Koichi Iwata and Ryo Nagata, which is a letter to the editor of the Journal of Applied Physics, Volume 60, January 1970.

This is a short but highly technical and mathematical piece which shows the feasability of determining the general three-dimensional distribution of refractive index from interferograms.

3. "Topographic Distribution of Refractive Indices in Bovine Lenses", by

Frederick A. Bettelheim and Tailer J. Y. Wang, in Experimental Eye Research, Volume 18, 1974.

The surface of the bovine lens was mapped for refractive indices by using the minimum of light scattered as a probe in different non-interacting media with different refractive indices. The highest refractive index is at the center and the refractive indices decrease symmetrically, moving toward the corner of the lens along either a horizontal or vertical axis. The authors concluded that in order to provide a uniform refractive power of the whole lens, the change in the curvature is compensated by a change in the refractive index.

4. "A Color Schlieren System Without Image Degradation", by Jurgen R. Meyer-Arendt, Louis M. Montes, and Willis S. Muncey, Jr., in the Journal of the Society of Photo-optical Instrumentation Engineers, Volume 9, number 1, October-November, 1970.

This explains that in German, a "schliere" is a local inhomogeneity. Thus, a Schlieren system is an optical system designed to detect local inhomogeneities. There are many examples of schlieren, occurring when hot water is mixed with cold, in the air above a hot roadway, and many other phenomena involving the presence of gradients in temperature, density, or pressure.

If light is passed through an inhomogenous, or schlieren, object, the differences in optical density will cause the light to be deflected. If a narrow, wedge type interference filter is then introduced, the deflected light will pass through different parts of the filter, depending on the prismatic action of the schliere. See figure 1. Where no schlieren are present, a background of the spectrum produced by the interference filter is formed.

Therefore, those elements in the object which deflect the light can be identified by different colors against a background.

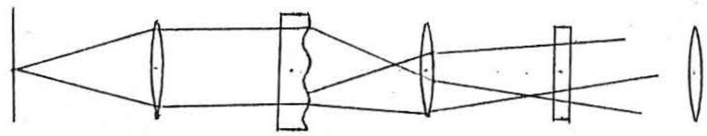

Fig. 1, reproduced by permission of Dr. Meyer-Arendt.

This last paper is the basis for the experimental arrangement of my research project. The optical system is modified and used for the thesis research.

EXPERIMENTAL METHODOLOGY

The project is divided into two steps:

1. Set up the basic apparatus and test with a test object.
2. Use bovine eyes in transmitted light.

Initially, the study involves a basic arrangement with some transparent test object to see if the method could be used for this research. This leads to step two, which involves the use of bovine eyes. The goal is to perfect the system to view and photograph the color images produced. Later on, perhaps it could be extended to humans and evaluating light reflected out of their eyes. Obviously, there is a long way between the basic set up and the use of humans, and because of the complexity, it could conceivably take two or more years to get to the human stage.

Step two is much more complex than step one, as there are inherent problems with isolation, mounting, and preservation of the organic crystalline lens during the time that it takes to run the experiment. The apparatus will probably have to be modified and adapted to this task.

RELEVANCY

Originally, two areas of study were of particular interest: 1. The difference in refractive index of the various parts of the crystalline lens, and 2. The variations that occur in optical thickness of the lens during accommodation. Further possibilities for study by this method include study of the presbyotic and cataractous lens.

METHOD AND PROCEDURES

STEP 1--Set up and test with a test object.

The apparatus was set up on an optical bench, approximating Dr. Meyer-Arendt's system.[4] See figure 2.

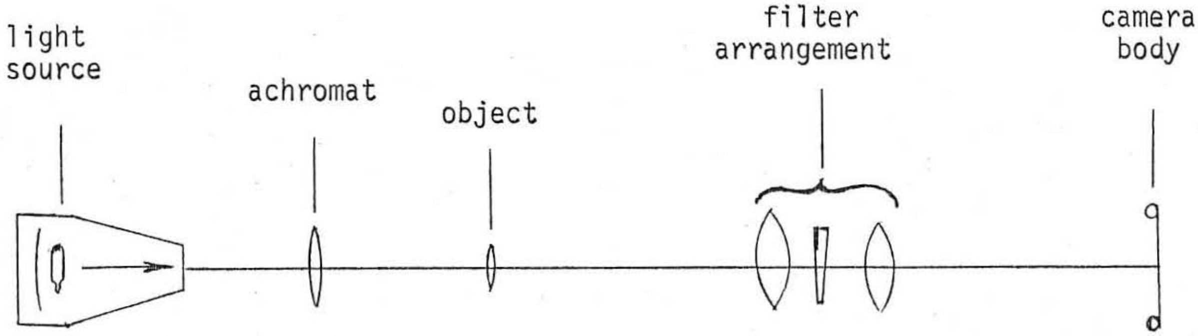

Fig. 2

The light source was a single housing containing a tungsten lamp with a mirror reflector, and tube extender on the front. Initially, no device for collimation of the light was used other than the tube extender on the light source housing combined with a 50 cm focal length (+2.00D) achromatic lens between the source and the test object.

The requirements of the test object were such that it be a clear material containing inhomogeneities in its structure. A number of objects were tried, with a clear plastic spoon being the final choice.

This arrangement yielded a poorly focused image of the spoon with a background of the entire spectrum of colors produced by the wedge filter. Although unsatisfactory, it was obvious that the variations in optical thickness in the spoon, due to its inhomogenous composition, were refracting light so as to displace it through the filter differently than a uniformly constructed, homogenous object. However, a more satisfactory image was needed.

Trying to obtain a better image, an improved collimating system was sought. This was accomplished by use of the system as shown in figure 3. A 9.8 cm focal length (+10.20D) lens directly following the tube extender, with a 10.5 cm focal length (+9.26D) lens 5 cm away, and after another 5 cm, an iris stopped down to approximately a 3 mm aperture size. Also, the 50 cm focal length (+2.00D) achromat was replaced by a 20 cm focal length (+5.00D) noncorrected lens.

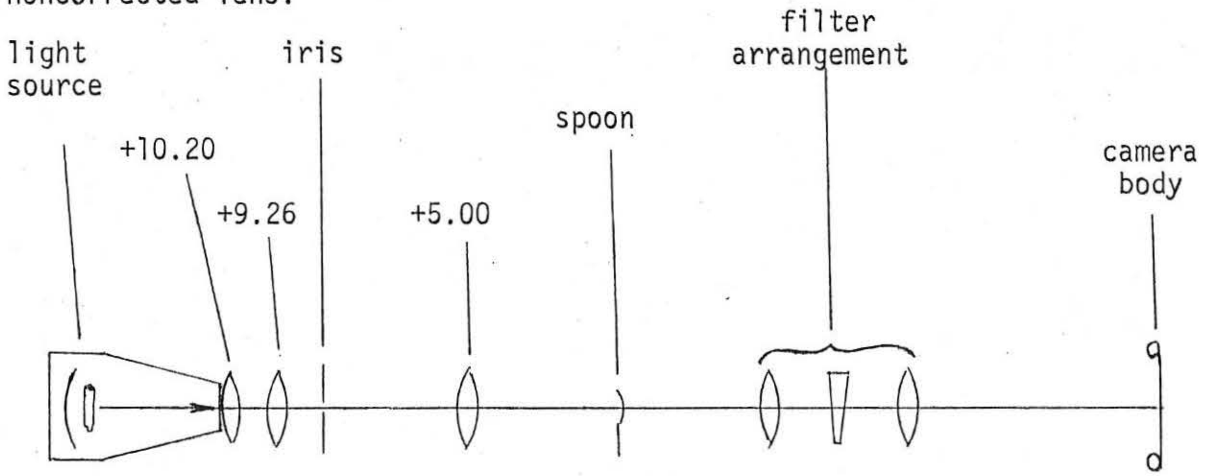

Fig. 3

This arrangement yielded changes to the image other than just an improved image of the object. The background could be limited to a small portion of the spectrum such that it appeared to be almost one color. This seemed to be more dramatic when viewing the color variations in the image against it. Also, by moving the 20 cm focal length (+5.00D) lens slightly from side to side, the color of the background could be varied. This also seemed to be useful in optimizing the effects of the variations in optical thickness of the object. The results obtained with this system appeared to be quite good.

Since later, the experiment would involve the use of a suspension medium in a glass container, at this time the spoon was put into the empty container to verify that the glass made no effect on the imagery. It did not.

Normal observations of the imagery were done using a piece of white cardboard, but a camera was used, in the same plane, for recording. The camera was a 35 mm single lens reflex body (Yashica TL Super). No lens was required on it as the optics of the experiment focused the image on the film plane. The film used was Tungsten High Speed Ektachrome in order to get good color rendition, since the source was a tungsten lamp. If any other type of light is ever used, another kind of film will probably have to be considered. Color transparencies were taken for recording, but prints were made of some of them for inclusion in the thesis.

STEP 2--Use of bovine crystalline lens.

This involved the acquisition of bovine eyeballs. They were obtained from Kummer Meats in Hillsboro, a slaughter house. And thanks are due Don Welle at Kummer for his cooperation. The eyes were procured only as needed in an attempt to insure as good results as possible. This meant that several trips had to be made and Don had to excise the eyes from freshly slaughtered animals. The eyes, usually still warm, were then placed in normal saline solution until they could be worked on in the lab. Some of the eyes did sit in the solution for as long as two days before being used, but most were used within two or three hours. This, admittedly, is not optimum. Since only the crystalline lens of the eye was needed, obvious problems arose. At first, removal of only the lens with the intact zonule fibers was considered, with the thought of suspending the lens by the zonules. This was unsuccessful because the fibers tended to separate from the lens rather than the ciliary body. The method was tried on only one eye, so perhaps it would be feasable with refinement of the technique. However, this one lens was taken to the apparatus to see how the image would be. It was found to be unsatisfactory when the lens was in air, and also when immersed in a solution of normal saline.

So, at this point there were still the two problems of what to use as a suspension medium for the lens and how to suspend it.

Dr. R. Yolton was very helpful here. He suggested using paraffin oil as a suspension medium, and leaving the lens suspended by intact ciliary body and zonule fibers, as he had done in previous experiments. Paraffin oil, white, was obtained from American Scientific and Chemical in Portland.

With the next eye, the extraocular fascia and muscles were removed, and the cornea and visible iris were excised. Then the globe was circumcised just posterior to the ciliary body and as much of the vitreous as possible was removed from the lens (it was quite tenacious, to both Dr. Levine's and my surprise). Excess sclera and choroid were trimmed away. Care was taken at all times to insure that no zonules were broken and that the lens was undisturbed. This operation left us with a ring of sclera, ciliary body, and zonule fibers suspending the lens--as close to au naturale as possible.

Now, what to do with this section of eye? How to suspend it in the medium? At first, a system of very small flat tipped alligator clips, covered with heat shrink tubing and hung from a small dowel was used, by clamping on to the scleral ring. This seemed cumbersome and crude, but some good slides were taken using this, and pictures are included. See figures 6 and 7.

A better, more professional method was devised, again through the suggestion of Dr. Yolton. A black plexiglass rectangle was machined to just fit inside the glass container. A 3/4 inch hole, slightly larger than the object lens, was drilled through the center. This was then beveled so that the scleral ring could rest on the beveled area, leaving the lens centered in the hole, suspended. The sclera was then attached to the plexiglass by very rapid bonding alpha-cyanoacrylate glue (similar to Krazy Glue). This arrangement was neat, clean, and easy. And it appeared to cause no adverse effects to the lens. The paraffin oil seemed to preserve the lens with no problems for much longer than the ten minutes necessary for the experiment to be run. After the short period of use, the section was easily removed from the plexiglass by a spatula or knife. Using this system, six more bovine lens images were photographed. The apparatus was arranged as shown in figure 4.

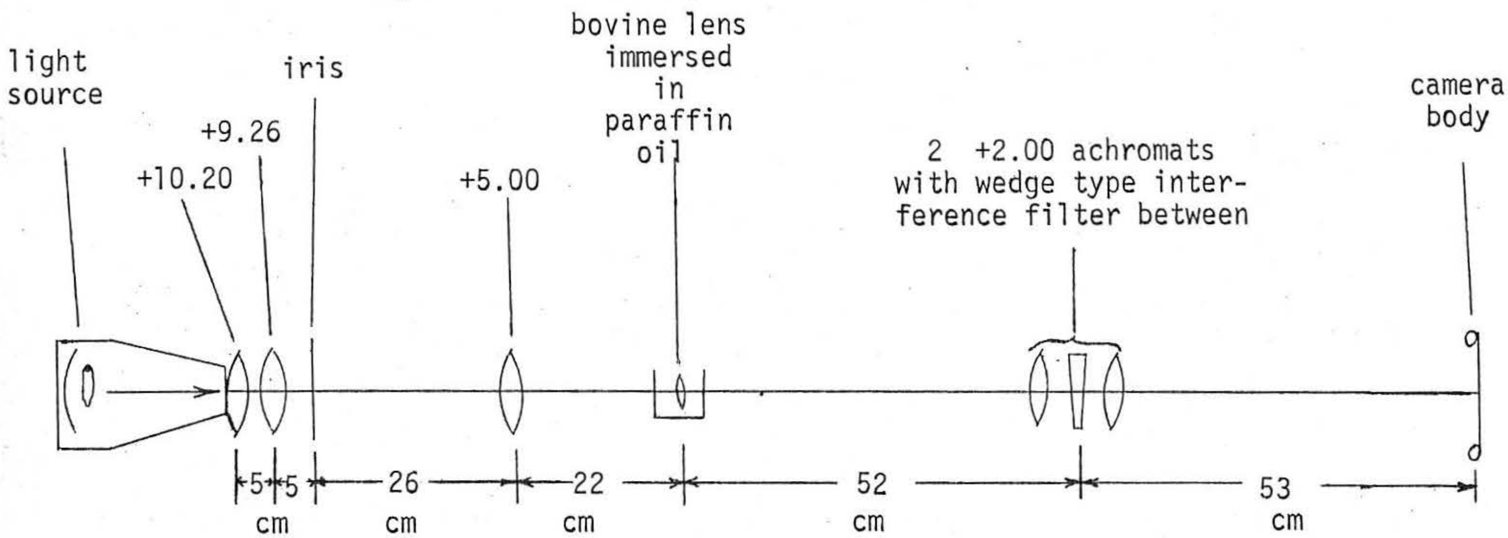

Fig. 4

At this time, a limitation of the color schlieren method, as used, was realized. When a conventional plus lens is inserted in the path, a spectrum of colors is seen within the lens.

With an inhomogenous lens, such as a human or bovine lens, which has in the center a higher index of refraction, it was originally hoped, as was stated, that refractive index changes in the material of the lens could be detected. It did not turn out this way. The reason is that the color interference filter is linear, so the background spectrum is stretched linearly also. To solve this it would be necessary to have an interference filter of circular symmetry, such as ONE Newton ring--but this is too far into the future. Still, the idea is valid that the method is perfectly suited for IN VIVO studies of refractive index, or better : optical thickness changes that occur under accommodation or in cataracts.

Next, a glass lens (in this case, a trial case lens) was sought which, in air, produced the same image size (16 mm) and color proportions as the bovine crystalline lens. An 18.887 cm focal length (+5.25D) lens did this. It was also found that the oil nearly neutralized the glass lenses. The most power that could be fit into the small glass chamber was with total lenses yielding a 1.887 cm focal length (+53.00D); the image size was approximately 30 mm. However, using lenses yielding a 1.923 cm focal length (+52.00D), a 32 mm image size was produced, twice that produced by the bovine lens, suggesting that lenses of about 104.00D would have given the correct image size. It will soon be shown why this is so.

Since the 18.887 cm focal length (+5.25D) lens in air, has effectively the same power as the bovine lens/paraffin oil/glass container system, it can be used whenever the apparatus is being used and the bovine lens is not absolutely necessary. This obviously greatly simplifies matters.

Next, the refractive index of the paraffin oil was determined. This had to be done since a chemist at one of the companies that manufactures the oil said that the index varies with each batch since it is a conglomerate of waste products from the manufacture of other chemicals. To determine the index, a hollow equilateral prism was made using three microscope slide cover glasses cemented together and to a microscope slide for a base. The paraffin oil was then poured into the setup, forming a paraffin oil prism. This was then put onto the prism spectrometer and the apex angles and angle of minimum deviation were found. The index was calculated using the formula:

$$\frac{\sin 1/2\ (a + d)}{\sin 1/2\ (a)}$$

where: a = apex angle

d = angle of minimum deviation

Via this procedure, the refractive index of the paraffin oil, for the green line of mercury, was determined to be 1.483 with an uncertainty of $\pm$ 0.002. Now it is obvious why the glass lenses were nearly neutralized by by the paraffin oil; the refractive index of the lenses is only 1.523.

Following the index determination, some measurements were taken. First, the useable size of the interference filter was found to be 5.0 cm. The size of the trial case lenses used were 3.6 cm. The separation of the colors on the interference filter corresponding to the colors in the slides were:

Blue - Green	0.59762 cm
Green - Yellow	0.80352 cm
Yellow - Red	0.883194 cm
Total (Blue - Red)	2.284334 cm

The separations of the corresponding colors in the slides were:

Figure 6

Blue - Green	0.3820 cm
Green - Yellow	0.3820 cm
Yellow - Red	0.1245 cm
Total (Blue - Red)	0.94465 cm

Figure 8

Blue - Green	0.2274 cm

Green - Yellow	0.2895	cm
Yellow - Red	0.3900	cm
Total (Blue - Red)	0.8169	cm

Figure 9

Blue - Green	0.3608	cm
Green - Yellow	0.2264	cm
Yellow - Red	0.4184	cm
Total (Blue - Red)	1.0056	cm

These lenses were selected because they gave the best images.

Nothing more can be done with these figures for two reasons: 1. The refractive index of the lenses is unknown (see the discussion, following), and 2. Due to using black plexiglass, there is no background spectrum so it is impossible to get ratios of background size to lens image size or deflection distances of the colors by the lens.

DISCUSSION

An interesting phenomenon was observed during the experiment. It was found that the bovine lenses caused inversion of the spectrum in the image. This indicates that the lens was functioning as a plus lens. In order to do this, the lens would have to be of greater index of refraction than the immersion medium. The index of the paraffin oil has been stated to be 1.483. According to the Bettelheim and Wang figures,[(3)] the average index of a bovine lens would probably be less than this figure. There are many variables involved, however, which may be factors in the difference: 1. The age of the animals was unknown; 2. The length of time the animal was dead, thus stopping nutrient flow to the lens; 3. The operation of removing the lens from the eye; 4. Any effect of the paraffin oil on the lens. In this case, it is most likely that the refractive index of the lens has changed, due to osmotic post-mortem factors, and thus was higher than it normally is.

For the future I see that the following things definitely could be improved upon from what was done here. The method of mounting the lens may be changed. Using the lens and zonule fibers only may be tried and the technique improved. Or, if a mounting similar to the one presently used is continued, a clear, homogenous material would be better than the black used here. In either type of mounting, the background could be seen for direct measurement of displacement of colors, and for determining ratios of background size to lens image size. The use of a different light source, such as a xenon lamp would perhaps produce significantly better results. Also, the ciliary muscle could be stimulated directly, electrically, to achieve accommodation and see what happens to the image. As for the reflected light part of the study, a slit lamp may be a possibility. The following is a possible arrangement for the apparatus in the reflected light part of the study.

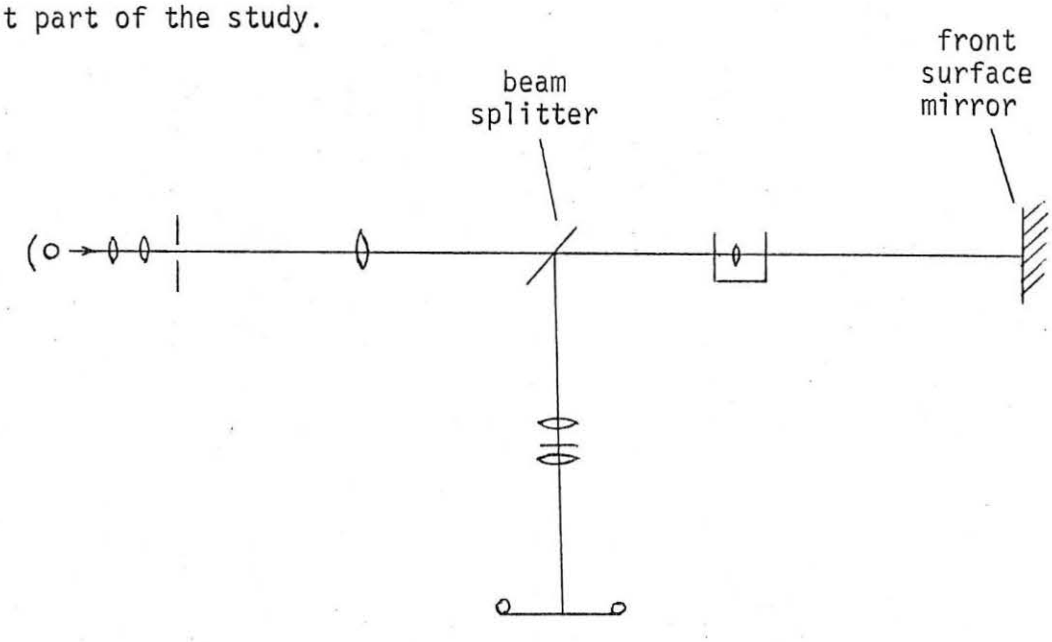

Fig. 5

Hopefully, the study will progress with someone else to develope a useful clinical tool for the observations of lens action in accommodation and possibly cataract progression.

BIBLIOGRAPHY

1. Nakao, Shuitu; Fujimoto, Shigeru; Nagata, Ryo; Iwata, Koiti
"Model of Refractive Index Distribution in the Rabbit Crystalline Lens"
Journal of the Optical Society of America, 58(8), Aug. 1968

2. Iwata, Koichi; Nagata, Ryo
"Calculation of Three-Dimensional Refractive Index Distribution from Interferograms"
Journal of Applied Physics, Volume 60, Jan. 1970, letter to editor.

3. Bettelheim, Frederick A.; Wang, Tailer J. Y.
"Topographic Distribution of Refractive Indices in Bovine Lenses"
Experimental Eye Research, Volume 18, 1974.

4. Meyer-Arendt, Jurgen R.; Montes, Louis M.; Muncey, Willis S., Jr.
"A Color Schlieren System Without Image Degradation"
Journal of the Society of Photo-optical Instrumentation Engineers, 9(1), Oct.-Nov., 1970.

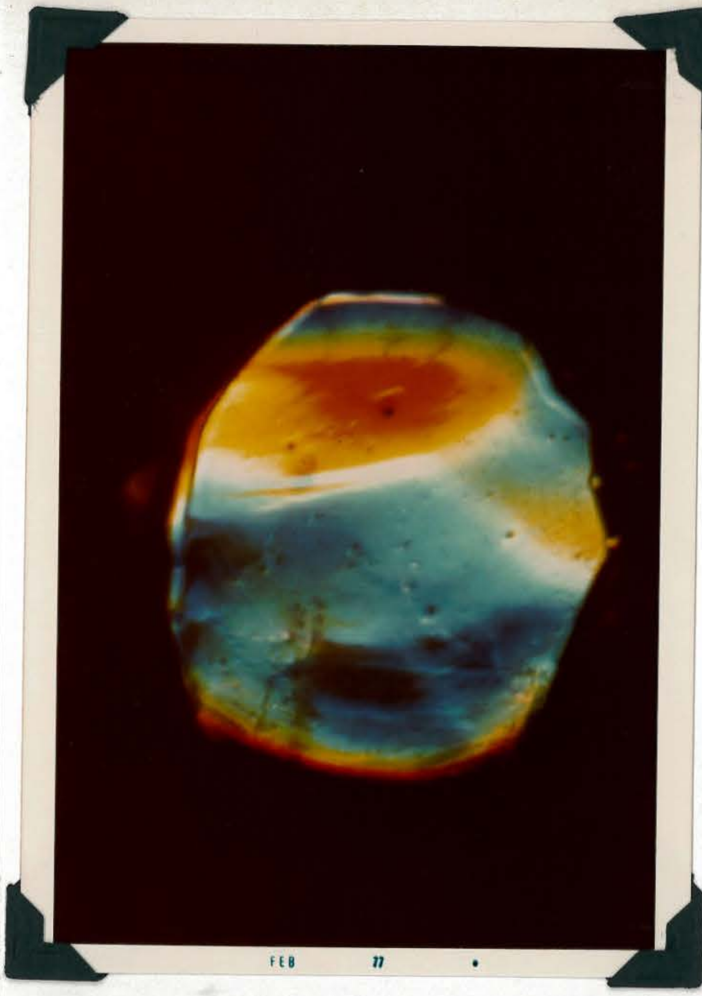

Fig. 6
LENS MOUNTED AS SHOWN IN FIG. 7

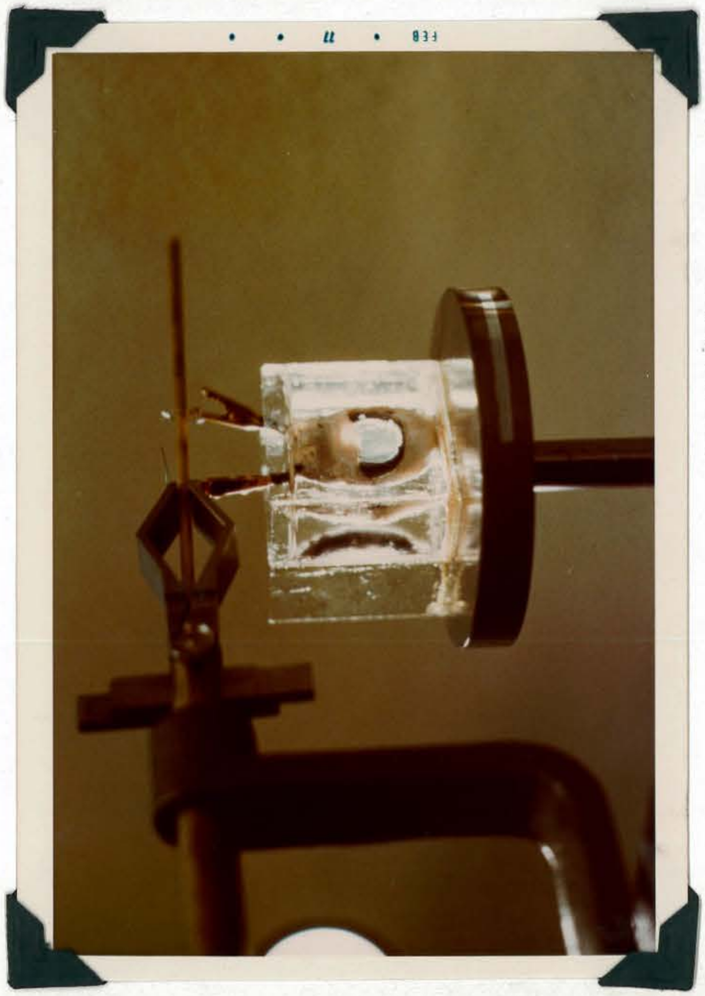

Fig. 7
MOUNTING METHOD, LENS OF FIG. 6

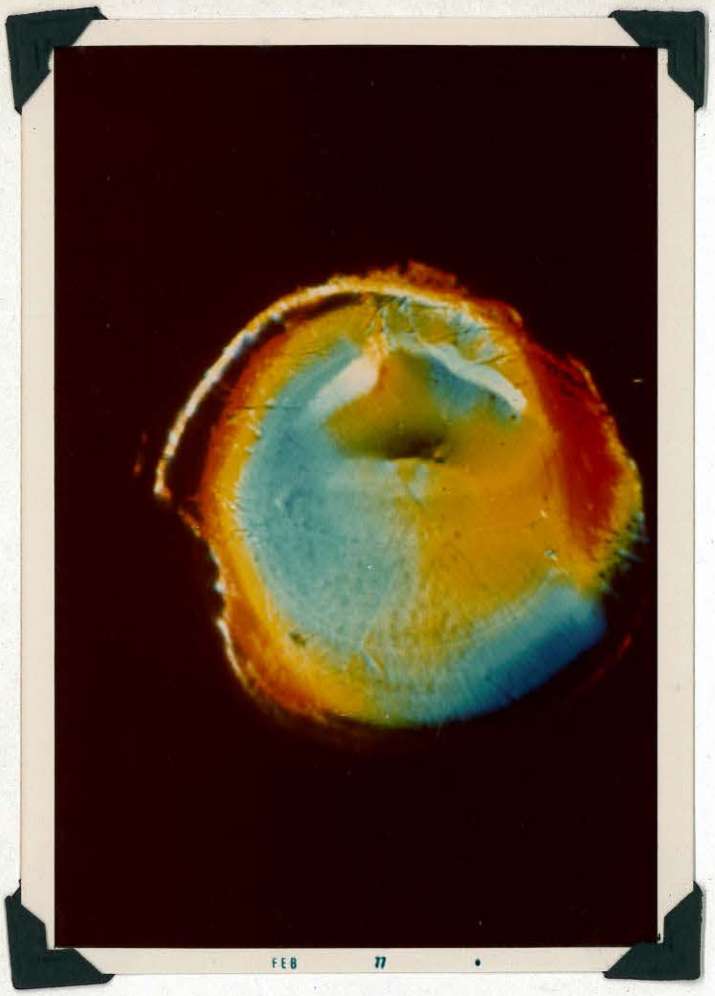

Fig. 8 A LENS MOUNTED AS SHOWN IN FIG. 10

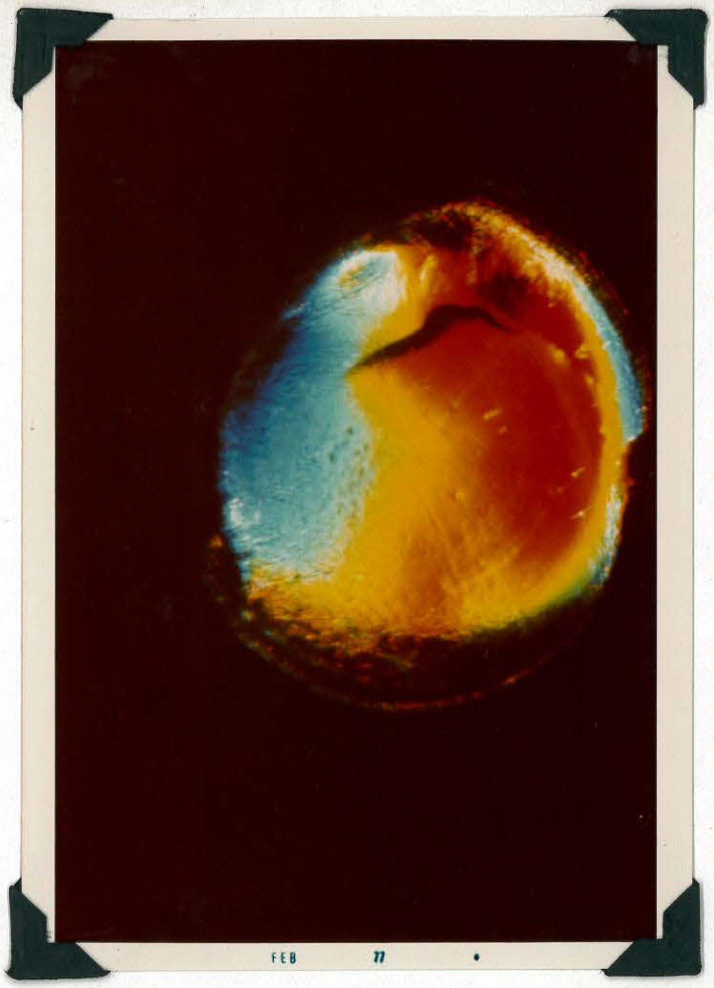

Fig. 9 A LENS MOUNTED AS SHOWN IN FIG. 10

Fig. 10 MOUNTING METHOD FOR LENSES IN FIGS. 8 & 9

BIBLIOGRAPHY

1. Nakao, Shuitu; Fujimoto, Shigeru; Nagata, Ryo; Iwata, Koiti
   "Model of Refractive Index Distribution in the Rabbit Crystalline Lens"
   Journal of the Optical Society of America, 58(8), Aug. 1968

2. Iwata, Koichi; Nagata, Ryo
   "Calculation of Three-Dimensional Refractive Index Distribution from Interferograms"
   Journal of Applied Physics, Volume 60, Jan. 1970, letter to editor.

3. Bettelheim, Frederick A.; Wang, Tailer J. Y.
   "Topographic Distribution of Refractive Indices in Bovine Lenses"
   Experimental Eye Research, Volume 18, 1974.

4. Meyer-Arendt, Jurgen R.; Montes, Louis M.; Muncey, Willis S., Jr.
   "A Color Schlieren System Without Image Degradation"
   Journal of the Society of Photo-optical Instrumentation Engineers, 9(1), Oct.-Nov., 1970.